Small-scale Forestry (2011) 10:53–66
DOI 10.1007/s11842-010-9130-2

Profit–Size Relationships: A Wood Value Expression to Facilitate Stand Management Decision Making

Michel Soucy · John A. Kershaw Jr.

Accepted: 20 August 2010 / Published online: 5 September 2010

Abstract This paper presents an alternative approach to expressing net value of wood in standing trees in relation to important tree characteristics. The approach aims at increasing woodlot owners' and managers' understanding of stand profit production and lead to consideration of stand interventions with higher profitability than those suggested by commonly used guidelines designed for maintaining biologically desirable stock levels. Our investigation showed that determining net wood value in individual trees for stand management purposes is not only feasible but relatively simple to do, requiring little additional information than typically used in stand level cash flow analysis. The presentation of wood value in the form of profit–size relationships presents two major improvements over traditional stand average values and product stumpage values: (1) it links both revenues and costs to determinant tree characteristics, providing a clearer picture of actual financial contributions of trees to stand value. (2) it gives the value of all wood grown and not just the value of volume sold. These two improvements allow landowners and managers to actually see where value is produced in specific stands, and design treatments accordingly to capture financial opportunities that would otherwise go unnoticed.

Keywords Stand management · Value production · Value of wood · Thinning · Profit–size relationship

M. Soucy (✉)
Forest Operations and Economics, Faculté de Foresterie, Université de Moncton, 165 Boulevard Hébert, Edmundston, New Brunswick E3V 2S8, Canada
e-mail: michel.soucy@umce.ca

J. A. Kershaw Jr.
Integrated Forest Management Laboratory, Faculty of Forestry and Environment Management, University of New Brunswick, 28 Dineen Drive, P.O. Box 4400, Fredericton, NB E3B 5A3, Canada

Introduction

No two stands are exactly alike, but with a few stand biological characteristics, one can find reasonable management schemes aimed at optimizing wood production using guidelines built to maintain biologically desirable stock levels. Financial characteristics are just another part of a stand's unique picture, but it has not been a common practice to summarize them into a few meaningful variables from which guidelines can be made and used to help direct stand management when the objective is profit. Instead, stand interventions aimed at increasing profitability are usually designed solely using wood production guidelines. Their profitability is then determined using cash flow analysis and the best is selected if it is deemed financially acceptable. Unfortunately, profitability measures currently used, such as net present value, only provide the outcome of the stand's expected value production, without information as to why it is so or how the management scheme could be modified to improve the outcome. There is a lack of practical procedures or rules for adjusting current management guidelines in order to ensure optimal economic stocking instead of biological stocking (Lu and Gong 2005).

Since value of wood produced in a stand depends on characteristics of individual trees (Zhang et al. 2006), it would seem logical that managing a stand for value production requires assessing and considering aspects that must be expressed at the tree level to be appreciated. Stand valuation, as traditionally performed, requires determination of wood products contained in individual trees, but does not require determining individual tree value. The resulting stand value does not give any indication of the contribution of individual trees on which wood is actually produced. Determining individual tree value and its conceptual utility is not new. Davis and Johnson (1987) and Davis et al. (2001) have devoted an entire chapter of their Forest Management textbooks to principles and methods of valuation to appraise an individual tree in terms of wood products. Nonetheless, explicit knowledge of individual tree net value to the landowner is not widespread, especially in relatively lower value species such as spruce. Landowners likely know the mean value of different log types, or understand the relative value of different trees, but rarely know the actual net profit of individual standing trees. This is not saying that economic objectives are not taken seriously, but rather that there exist difficulties that prevent using standing tree value in stand management decisions which leaves finding profitable management schemes a matter of chance. Furthermore, many seem to believe that because net value of individual trees is so context specific, it must be too complex and too time consuming to be worthwhile.

Currently it is common to have regional stumpage values representing average net value of timber to the landowner given current economic contexts (for example, see Anonymous 2008). Stumpage is based on the difference between selling value of products and stump-to-market processing costs (Davis et al. 2001). Stumpage is determined and used mainly to set the price of wood to be paid to the landowner and not for stand management purposes. As such, it does not require being presented based on tree characteristics, but is better served when presented at the level of products sold. Such presentation of stumpage value causes two problems: (1) the

value of a product is an average for the stand, hence, assumes that it is the same regardless of the tree it came from. For example, the value per cubic meter of a pulp log will be the same whether it comes from a large or a small tree. (2) Not all volume grown is given a value. Stumpage value usually presents value of wood recovered only. It is uncommon to determine the average value per cubic meter of total volume (i.e. the volume that actually grew in a stand as opposed to the volume that was deemed merchantable and sold). Costs incurred on "non-commercial" trees or tree sections are distributed among volume sold. It follows that stumpage is not always useful for determining which trees should be harvested, if any, to increase overall value production.

For stand management purposes, that information is important since it is all the volume produced that is being managed and not only the merchantable portion. In other words, the cut or leave decision is made for both merchantable and nonmerchantable trees, hence, the net financial contribution of all trees should be considered.

This paper presents an efficient and flexible approach to determine net value of wood in standing trees in relation to important tree characteristics. The approach is applicable to most stand types and regions across the world. It should be of particular interest to small landowners trying to manage their parcel for profit production. The purposes of this paper are to demonstrate how relating net value of wood in standing trees to stem characteristics can (1) improve understanding of stand profit production, and (2) lead to the consideration of stand interventions with higher profitability than those suggested by commonly used guidelines. The concept of profit–size relationships is first presented, then the usual procedure for cash flow analysis is reviewed and modified to extract net value of wood in standing trees as functions of stem characteristics.

Characteristics of the Example Stand Used to Demonstrate the Profit–Size Relationship Concept

As an example to be used throughout this paper, the tree and stand value of a spruce plantation is determined and analysed. The example stand is a 40-year-old white spruce plantation whose diameter distribution is detailed in Pelletier and Pitt (2008). In brief, the stand is considered to be immature and very dense (2,204 trees/ha; 48.7 m^2/ha of basal area and 279 m^3/ha in total volume). The stand is assumed to be located in a woodlot in northwest New Brunswick, Canada. Revenues from wood in that area are obtained from sales of logs delivered to a local pulpmill (17 km from woodlot) or sawmill (57 km from woodlot). Log values are set at prices offered for logs in June 2008 (Table 1). Expected product recovery (m^3/stem) per dbh class were derived from Honer (1983) volume equations for white spruce given the product lengths and minimum diameters presented in Table 1. Timber is felled and processed manually using a chainsaw and skidded to roadside using a large farm tractor and self-loading trailer. Logs are then delivered to the mills using self-loading trucks. As such, costs used for the ongoing example (Table 2) were derived from regional average hourly costs for 2008 in northwest New-Brunswick. Felling,

Table 1 Product characteristics, sale price (based on June 2008 NB delivered prices) and volume recovery for the example stand

	Product characteristics				
	Length (m)	Top diameter inside bark (cm)	Sale price ($/m^3)	Volume recovery (m^3/ha)	Revenue ($/ha)
Pulplogs	1.22	6	44.40	47.5	2,111
Studlogs	2.59	10	45.64	83.4	3,807
Sawlogs	3.81, 4.42, or 5.03	15	59.00	93.9	5,537
Total				224.8	11,455

Table 2 Harvesting and transport costs used in the example white spruce plantation

	Felling and bucking	Skidding	Transport to pulpmill	Transport to sawmill	Total
Hourly cost ($/pmh)	33	90	115	115	
Productivity (m^3/pmh)	2.0	12.0	17.0	14.0	
Merchantable vol. (m^3/ha)	225	225	48	177	
Total ($/ha)	4,397	1686	304	1,456	7843
Average ($/m^3)	19.56	7.50	6.39	8.21	34.89

processing and skidding productivity numbers used were adapted from productivity results provided in the software Interface 2003 (Forest Engineering Research Institute of Canada, Pointe-Claire, Canada). Transport productivity was derived from distances and travel speeds between the woodlot and mills. The overall result is a liquidation value that corresponds to 3,612 $/ha which averages to 16.07 $/m^3 sold but only 12.96 $/m^3 grown.

Profit–Size Relationships: Net Value of Wood as a Function of Stem Size

Just as stand value is bound to tree characteristics for product recovery and some costs, individual tree value is bound to stand level characteristics. In both cases, the process of valuation requires bringing all costs and revenues to a common denominator. The choice of denominator, whether it is land or trees, does not have any influence on required information, but influences the information conveyed. Presenting value of a single tree doesn't pose a problem, but presenting a list containing thousands of individual tree values would be practically useless for stand management purposes.

For individual tree values to be of any use, the list of trees contained in a stand must be grouped sufficiently to be interpretable. At minimum, trees should be classified in terms of stem volume or some proxy variable such as dbh. Because stands grow a certain amount of wood annually, which is distributed among trees, management decisions mostly revolve around determining which trees should be

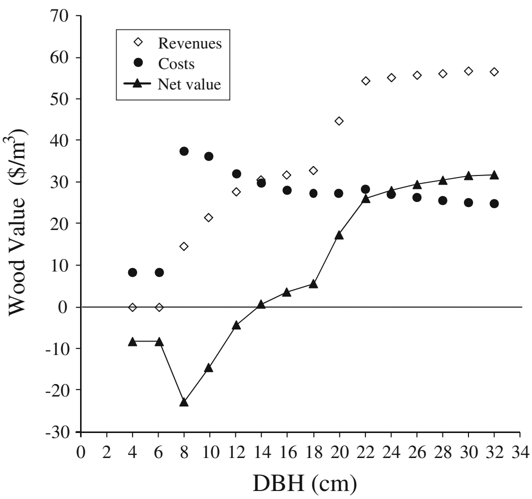
receiving that growth. It follows that knowledge of actual change in value of trees following a change in stem volume is at the base of stand management decisions when value production is a goal.

Classifying trees solely based on stem size is sufficient for stands composed of trees having relatively low value, simple stem form, and simple end-product specifications (i.e. many softwood species). In other instances, such as in tolerant hardwood stands, tree value varies greatly between trees of the same size. Trees should then be further classified according to factors causing changes in value as long as they are factors that can be evaluated during stand interventions. If a land manager cannot tell the different contributions of individual trees to stand value production, then the ability to determine which are worthy of future growth is greatly reduced.

Profit–size relationships are stand-specific relationships describing net value of wood in standing trees in relation to stem size (Figs. 1, 2). Profit–size relationships allow managers to concretely see how the stand's financial characteristics translate to the tree level. It is important to understand that such relationships are context specific, and that there can be multiple profit–size relationships for a single stand since landowners can consider different value recovery chains (i.e. processes used to prepare the wood for sale). The value recovery chain considered is limited to the processes used by the landowner, which contrasts with typical industry wide value recovery chains that accounts for all processes used to produce a set of end products, including factors other than landowners. Generating profit–size relationships for different product recovery chains considered can quickly and easily illustrate differences at the tree level. Figure 2 is a good example, using realistic values, of the difference in value of wood of the same trees when considering two different harvest prescriptions: a clear-cut and a partial cut.

Determining a profit–size relationship is essentially a decomposition of stand profit. The information required is the same as for traditional cash flow analysis. The procedure is similar to the residual value approach to stumpage valuation proposed

Fig. 1 Value of wood grown as a function of dbh in white spruce plantation



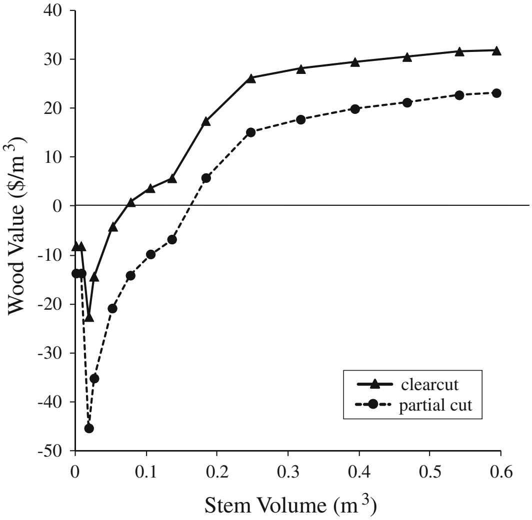


Fig. 2 Profit–size relationship for clear-cut and partial cut prescriptions

by Hotvedt and Straka (1987) but applied to a specific context instead of regional values. The procedure starts with value of end products sold by the landowner, whether it's simply standing timber or a variety of end products such as lumber and woodchips. The importance here is to obtain the value that the landowner would receive. This differs from Hotvedt and Straka's (1987) procedure, where, instead, they start with end products in a well defined market in an attempt to generate a tree value applicable in a more general context. Next, product recovery (i.e. volume of each end product that can be obtained) is determined as a function of total stem volume. Product recovery is then multiplied by value of end products, giving revenue per stem. Revenue per stem can then be divided by total stem volume to obtain the average revenue per cubic meter of wood as a function of stem size. Using total stem volume instead of recovered (merchantable) volume gives the value of volume grown (i.e. the value of growing a cubic meter of wood in trees of that size class).

Unlike revenues, costs are not only tied to sale of end-products, but are also subject to factors such as area treated or need to construct a road. Furthermore, costs are also influenced by landowner's choice of product recovery chain (i.e. equipment and method used) and characteristics of the stand in which the trees grew. This means that while maximum revenues obtainable from a given tree are theoretically the same for all landowners, costs are not. It follows that net value of wood, to the landowner, is very context specific.

Cost information required for profit–size relationships are no different than in other cash flow analyses except that it is presented as a function of stem size. It is important that all costs related to the stand's management be included in the profit–size relationship. Fixed costs come as a total value for the stand ($/ha) which must be converted into wood volume fixed costs ($/m^3) value. To do so, fixed costs ($/ha) are divided by the volume to be harvested (m^3/ha). This will attribute the same amount of fixed cost per cubic meter of wood regardless of the stem size. On the

other hand, this will modulate the fixed cost according to the volume harvested resulting in higher fixed costs per cubic meter of wood in partial cuts compared to clear-cuts (Fig. 2). Variable-production driven costs, such as transport costs to mills, come as a value per cubic meter ($/m^3). If they are applicable to a specific portion of stems (i.e. certain log types), product recovery per stem size class must be determined to identify the proportion of stem volume subject to that cost. A change in product recovery with stem size will see an equivalent change in variable-production driven costs with stem size. Variable-productivity driven costs, such as harvesting costs, come as an hourly cost where a tree's total cost depends on time spent processing it which is often function of stem size. The hourly cost divided by processing productivity per size class (m^3/pmh) gives the required cost per size class. If a landowner does not have all the necessary cost information, this will result in less accuracy in the generated profit–size relationship, just as it would in any other cash flow analysis that requires estimating costs.

Like revenues, costs should be presented as a function of volume produced and not only of volume sold. Traditionally, costs incurred on nonmerchantable volume are distributed evenly among the merchantable volume harvested, effectively hiding their influence. Presenting costs per volume unit grown solves that problem and gives a more accurate picture of the consequences of intervening on different tree sizes. Note that costs assigned to a given tree do not necessarily occur on all its volume. While the entire tree is felled, often only a portion of it is transported to mills. Nonmerchantable trees, for their part, are felled without further processing, explaining the lower cost per cubic meter of the smallest trees in Fig. 1.

Finally, the profit–size relationship is completed by subtracting costs from revenues. If some of the value information used is discrete instead of being a continuous function of stem size, the resulting profit–size relationship must also be discrete to ensure proper interpretation (Palahi and Pukkala 2003). For our ongoing example, the actual relationship was only determined for discrete points but lines were added to facilitate viewing. In Fig. 2, the profit–size relationships are presented as a function of total stem volume instead of dbh. Using stem volume instead of dbh makes it easier to see the influence on wood value of growing a stand by a given volume per hectare or of concentrating growth on certain trees sizes.

Profit–size relationships can also be determined for a range of tree sizes beyond those actually present in the stand. When developing profit–size relationships, expected product recovery can be based on physical tree characteristics obtained from trees actually in the stand or from regional mean tree descriptions. Basing profit–size relationships on trees actually in the stand can potentially provide a better sense of current stand profit, but obtaining that information would require tree measurements more detailed than what is commonly obtained in stand inventories. More importantly, it would not provide information on trees of sizes not actually in the stand. Basing profit–size relationships on physical characteristics of "average" trees is essentially applying stand specific cost and revenue functions to tree descriptions not necessarily in that stand. The resulting profit–size relationship shows what the entire range of tree sizes would be worth if it was to be harvested from that stand. This profit–size relationship is more informative and requires less intensive tree measurement, but average trees likely differ in value from those in the

stand because of differences in stem form. Nonetheless, these profit–size relationships are more representative than the more common "price–size" relationships presented by Mitlin (1987) where product recovery, product value, and all costs are regional averages. Like cash flow analysis, a certain level of uncertainty is inevitable.

Utility of Profit–Size Relationships

Profit–size relationships first serve as an eye-opener into the distribution of value among trees within a stand. It clearly indicates marginal tree size (size for which trees can be harvested without loss) given different recovery chains considered (Price 1989). In our example stand, the marginal tree size was 14 cm dbh (0.08 m^3/stem) in the clearcut scenario and 20 cm (0.18 m^3/stem) in the partial cut scenario (Fig. 2). Profit–size relationships indicate which tree sizes are not worth extracting, even if they contain merchantable volume. It also indicates if certain tree sizes are really more profitable, and whether increasing tree size actually secures increased benefits. The process of producing the profit–size relationship also simultaneously generates value of each type of end product produced in relation to tree size (Table 3). In our example stand, this showed studlogs to always have a lower net value than pulplogs, hence suggesting that studlogs should be marketed as pulplogs instead. Profit–size relationships allow landowners to quickly and easily evaluate the immediate impact on cash flow of cutting or harvesting a given tree size.

Table 3 Value of wood per log type, treatment, and diameter class

dbh (cm)	Value of wood from clearcut ($/$m^3$)			Value of wood from partial cut ($/$m^3$)		
	Pulplogs	Studlogs	Sawlogs	Pulplogs	Studlogs	Sawlogs
4	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00
8	−69.00	0.00	0.00	−137.85	0.00	0.00
10	−29.84	0.00	0.00	−72.57	0.00	0.00
12	−6.56	−7.14	0.00	−33.77	−34.35	0.00
14	1.43	0.85	0.00	−20.46	−21.04	0.00
16	5.46	4.88	0.00	−13.75	−14.33	0.00
18	8.28	7.70	0.00	−9.04	−9.62	0.00
20	13.12	12.54	25.90	−0.97	−1.55	11.81
22	17.34	16.76	30.12	6.06	5.48	18.84
24	18.50	17.92	31.28	8.00	7.41	20.77
26	19.42	18.84	32.19	9.52	8.94	22.30
28	20.09	19.51	32.87	10.65	10.07	23.43
30	20.64	20.06	33.42	11.57	10.99	24.34
32	20.97	20.39	33.75	12.12	11.54	24.89

The second utility seen for profit–size relationships is its use for determining and understanding potential of improving a stand's profitability with thinning. In brief, thinning is a partial cut in dense stands which concentrates future volume growth on fewer trees, resulting in bigger trees at final harvest. Since thinning does not significantly increase total volume production, wood produced in thinned stands must be more valuable for thinning to be profitable.

The example stand reaches its maximum net present value of 4,386 $/ha at 55-years old (assuming a 3% discount rate). The Stand Density Management Diagram software (OMNR 2001) puts the stand in the middle of the zone of imminent mortality meaning that it is under intense competition due to its high density. The stand is well within the guidelines for commercial thinning cited in the forest management manual for New Brunswick crown land (a minimum basal area of 14 m^2/ha after thinning, and a thinning intensity of a maximum of 40% removal of total basal area). Biologically, the stand would be a good candidate for thinning from below removing 35% of basal area as commonly performed. Financially, traditional net present value analysis shows that overall stand profit is reduced to 4,361 $/ha (Table 4). The disappointing financial outcome is not the result of a lack of growth response because the simulated results showed an overall increase in stand volume produced, which is optimistic when compared to most growth and yield studies.

Presenting costs as being too high for revenues obtained is not an explanation for the lack of profitability obtained, but rather a simple repetition of the net present value analysis. On the other hand, careful analysis of profit–size relationships and stand characteristics shows that thinning had little potential to improve the stand's profitability (Fig. 3).

Since financial success of thinning revolves around its capacity to produce bigger trees which are deemed more valuable, the first step in determining potential profitability of thinning is to verify that bigger trees would actually be worth more. While the price–size relationship shows that wood from 32 cm dbh trees is worth much more than that of 10 cm dbh trees, this in itself does not mean that thinning can produce more valuable wood even if it produces bigger trees. To verify that

Table 4 Evolution of stand value for thinned and unthinned stand scenarios

Age (year)	Net present value[a] ($/ha)						
	Unthinned stand	Thinning from below	Residual stand thinned from below	Overall thinning from below	Custom thinning	Residual stand custom thinned	Overall custom thinning
40	3,612	−736	3,086	2,350	−497.7	3,089	2,591
45	4,384		4,395	3,760		4,400	3,971
50	4,289		4,133	3,586		4,137	3,767
55	4,386		4,833	4,361		4,847	4,527
60	4,060		4,615	4,207		4,625	4,349
65	3,888		4,041	3,689		4,049	3,811

[a] Discount rate of 3%

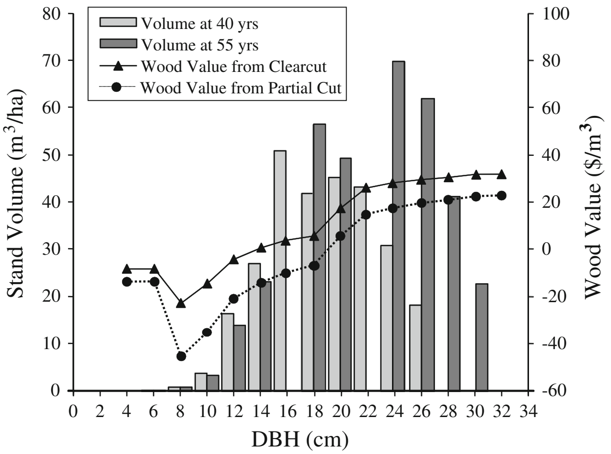


Fig. 3 Combined stand volume distribution and profit–size relationship

thinning has potential to increase profitability, one must look at the volume distribution expected for the stand (unthinned) at time of final harvest simultaneously with the profit–size relationship. For this example, most of the stand's volume at time of final harvest is expected to be in trees 24 cm dbh or greater. The profit–size relationship in a clear-cut, which is applicable at final harvest, indicates that this volume will have reached close to its maximum value. In other words, this portion of stand volume cannot increase in value following an increase in tree size due to thinning. Roughly 105 m^3/ha (30%) of the stand's final volume is in 18–20 cm dbh trees. This volume would see its value increase by approximately 10 $/$m^3$ with a 2 cm dbh increase and would be close to the maximum wood value. The stand's volume in 12–14 cm dbh trees is relatively small and generates close to a null profit per cubic meter. The stand's volume in 8–10 cm trees is very small and should not be extracted at time of harvest since it is not even worth its transport cost. Given the final volume distribution, only a relatively small portion of the stand would benefit from an increased tree size. Comparing the clear-cut profit–size relationship with the partial cut profit–size relationship shows that harvesting wood during thinning reduces the value of wood between 8 and 23 $/$m^3$, and increases the marginal tree size to somewhere between 18 and 20 cm dbh indicating that thinning from below is likely to result in a negative cash flow. The relatively small increase in value that can be expected from the mid-sized trees compared to the extra cost for harvesting wood in thinning greatly reduces any potential for thinning to be profitable. Finally, thinning would reduce volume lost to mortality that is expected to occur in the smallest trees due to competition, hence effectively increase volume in small trees harvested (at a net cost) throughout the stand's life. In brief, the current profit–size relationships for this stand imply that thinning this stand from below, as commonly performed, has little potential for profitability, regardless of how well the stand fits into biological thinning guidelines. Thinning could have been profitable if the value from sawlogs would have been higher, creating a larger increase in value of trees 20 cm dbh and greater.

Finally, profit–size relationships can be used to design or modify stand interventions specifically to increase profitability. For our example, current management guidelines suggest thinning the stand from below to optimize its biological stocking level for volume production. Thinning from below, as commonly performed, would essentially harvest most trees at a high net cost per cubic meter since the removal of trees between extraction trails focuses on the smallest trees. Based on the profit–size relationships in Fig. 3, it can be worthwhile to consider a slightly modified thinning prescription. Trees 14 cm dbh and smaller would still be cut but left in the woods since they cost more to extract than they are worth. All trees 16 cm dbh and above between trails would be left intact because they show the greatest potential for increase in value. This custom thinning prescription results in a harvest intensity slightly less than 35 % of the basal area and slightly reduces volume sold at time of thinning. On the other hand, the custom designed treatment increases net value of the thinning itself and overall profitability is increased over traditional thinning from below (Table 4). Furthermore, the increased value of the thinning itself reduces the burden on the residual stand since it does not have to increase in value as much in order for the management scheme to be profitable (i.e. it reduces the risk). Designing custom treatments aiming at value production could not be efficiently done without the information provided by profit–size relationships.

Tree-Profit Matrix: Net Value of Wood as a Function of Multiple Factors

Relating profit to a single tree characteristic is an improvement on presenting profit as a mean cubic meter value for the whole stand, but falls short of capturing all factors. In stands composed of trees whose value varies greatly between trees of same size, it may be necessary to present value of wood as a more complex function. Determining value of wood in standing trees then requires trees to be further classified according to relevant quality factors, i.e. those that cause significant changes in value. The challenge is in finding a simple way of presenting net value so as to be meaningful and usable for stand management decisions. Perhaps, the more complex wood value is, the greater the potential benefits of calculating net value of wood at the level where it is being managed and in a manner that can be seen/measured by land managers.

For example, the Algonquin region tolerant hardwood four-class tree classification concept (OMNR 1998) could serve as a complement to tree size upon which value of wood can be presented. This classification system separates trees in four groups according to quality of logs they contain or are capable of producing. Tree class “A” represent the best trees containing or capable of producing high-quality logs while tree class “D” represent cull trees that have no sawlog potential.

An example of a tree-profit matrix is presented using sugar maple (*Acer Saccharum* Marsh.) sold as logs at roadside (Fig. 4). Expected log volume recovery per tree size was determined using Honer (1983) volume equations and the log specifications shown in Table 5. Average log quality recovery was determined using local expertise and unpublished results (Martin Lepage, personal communication,

Fig. 4 Net value of wood in standing sugar maple trees as a function of dbh and tree quality

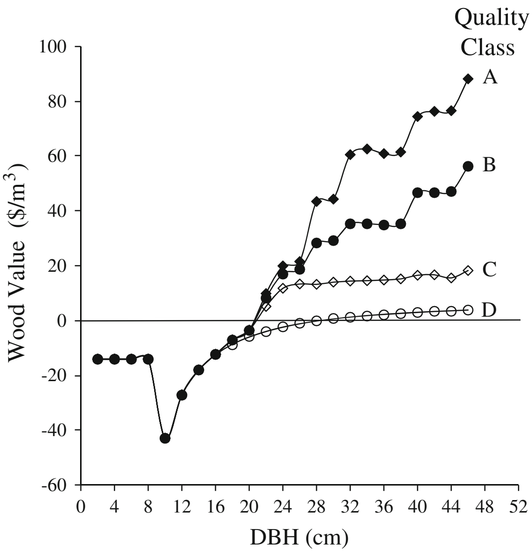


Table 5 Log specifications for sugar maple

Grade	Min. top dia. (cm)	Length (m)	# Clear face	Price ($/m^3)
Sawlog	36	2.54	4	180
			2–3	120
			0–1	45
Sawlog	24	2.54	4	125
			2–3	75
			0–1	40
Sawlog	18	2.54	4	55
			2–3	50
			0–1	40
Pallet log	15	2.54	0+	20
Pulp log	10	2.54	0+	16

Université de Moncton, July 9, 2008). Cost of felling, skidding and processing where determined for a mechanized, partial-cut, full-tree operation using Interface 2003 (Forest Engineering Research Institute of Canada, Pointe-Claire, Canada).

The resulting tree-profit matrix conveys much information useful in determining stand management prescriptions based on financial characteristics. For this example, it is clear that even if trees from 10 to 20 cm dbh have logs acceptable for the current market, the net value of harvesting such trees would result in a net loss, regardless of tree quality. In fact, within that size range, no net value difference is observed between tree quality classes. In that context, recuperating mortality of dead trees smaller than 22 cm results in a waste of financial resources instead of preventing it. It is also interesting to notice that it is within that size range that occur

the most abrupt increase in value with increase in stem volume. It is obvious that trees from 10 to 16 cm dbh of all quality classes would greatly increase in value with any increase in size. Low quality trees (class C and D) quickly reach their maximum value (dbh of 20–24 cm) at a net value near zero while trees of quality classes A and B continue their value increase. Priority of harvest should be on large trees of quality A and B that are of poor vigor or at risk of deteriorating in quality prior to the next harvest. Large trees of quality classes C and D should also be harvested to favor growth on trees that will show a better value production rate.

Conclusion

Determining individual tree net value for stand management purposes is not only feasible but relatively simple to do, requiring little additional information than typically used in cash flow analysis. The presentation of net value of individual trees presents two major improvements over traditional stand average values and product stumpage values: (1) it links both revenues and costs to determinant tree characteristics, providing a clearer picture of actual financial contributions of trees to stand value; (2) it gives the value of all wood grown and not just the volume sold. These two improvements allow managers to actually see where value is produced in the stand, and design treatments to capture financial opportunities that could otherwise go unnoticed. Presenting wood value in relation to specific tree characteristics, wether it is simply tree size or some matrix of characteristics, helps foresters and landowners because it presents value of wood at the level where its being managed, can be seen, and measured. Profit–size relationships and Tree-profit matrix do not intend to replace cash flow analysis but rather to complement it by providing some explanations for their outcome and a tool to improve the search for more profitable interventions.

The expression of net value of wood in the form of a profit–size relationship appears to be particularly well suited for analyzing the influence of wood value on thinning profitability. Two reasons guide this affirmation: (1) it is a simple, all inclusive, representation of wood value; (2) it relates wood value to stem size, which is known to be greatly influenced by thinning.

The determination and use of profit–size relationships appears to be especially well suited in a context of small-scale forestry. The sale of wood is generally a means to smaller landowner's objectives, which often includes profit production. Profit–size relationships offer a means of presenting common cost and revenue information such as to improve a landowner's understanding of profit production in its specific context.

Future work should be directed in two areas: (a) describe the common forms and magnitude of profit–size relationships; (b) analyze and interprete the implications of the common profit–size relationships on stand interventions profitability. Particularly, profit–size relationships appears to be well suited to offer insight into profitability of thinning treatments since thinning's main influence is on stem size harvested.

Acknowledgments Special thanks to Martin Lepage, ing.f. and Martin Béland, Phd. for access to unpublished data and valuable recommendations. Thanks to Dr. Ted Needham; Dr. Van Lantz and to reviewers for suggestions and comments on the manuscript. Financial support for this research was provided by the National Sciences and Engineering Research Council of Canada (NSERC) and the Université de Moncton.

References

Anonymous (2008) 2007 Stumpage prices by Maine county. Department of conservation, Maine Forest Service, Forest Policy and Management Division, 22 p.

Davis LS, Johnson KN (1987) Forest management. McGraw-Hill, Montreal, p 790

Davis LS, Johnson KN, Bettinger P, Howard TE (2001) Forest management; to sustain ecological, economic, and social values. Waveland Press, Inc, Long Grove, p 804

Honer TG, Ker MF, Alemdag IS (1983) Metric timber tables for the commercial tree species of central and eastern Canada. Canadian Forestry Service, Environment Canada. Information Report M-X-140, 139 p.

Hotvedt JE, Straka TJ (1987) Using residual values to analyse the economics of Southern pine thinning. Southern Journal of Applied Forestry 11:99–106

Lu F, Gong P (2005) Adaptive thinning strategies for mixed-species stand management with stochastic prices. Journal of Forest Economics 11:53–71

Mitlin DC (1987) Price-size curves for conifers. Forestry Commission, Planning and surveys division, Great Britain. Bulletin 68, 14 p.

OMNR (1998) A silvicultural guide for the tolerant hardwood forest in Ontario. Toronto, Ont. Min. Nat. Resour. Queen's Printer for Ontario, 500 p.

Palahi M, Pukkala T (2003) Optimising the management of Scots pine (*Pinus sylvestris* L.) stands in Spain based on individual-tree models. Ann For Sci 60:105–114

Pelletier G, Pitt DG (2008) Silvicultural responses of two spruce plantations to midrotation commercial thinning in New Brunswick. Can J For Res 38:851–867

Price C (1989) The theory and application of forest economics. Basil Blackwell Ltd, Oxford, p 402

Zhang SY, Lei YC, Jiang ZH (2006) Modelling the relationship of tree-level product value with tree characteristics in black spruce. For Chron 82(5):690–699